POWER QUALITY IMPROVEMENT USING MULTILEVEL INVERTER BASED SHUNT ACTIVE FILTER

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

Master of Technology

In

Power Control and Drives

By

Mandava Divya Prafulla

Department of Electrical Engineering

National Institute of Technology

Rourkela

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Under the Guidance of

Prof. Anup Kumar Panda

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DECLARATION

I hereby declare that the work in the thesis entitled "Power Quality Improvement Using Multilevel Inverter Based Shunt Active Filter" presented by me in partial fulfillment of the requirements in partial fulfillment of the requirements for the award of Master of Technology Degree in **Electrical Engineering** with specialization in **"Power Control and Drives"** at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by me. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree or diploma

Date-23-05-2015 Mandava Divya Prafulla

National Institute of Technology
Rourkela

CERTIFICATE

This is to certify that the thesis entitled, **“Power Quality Improvement using Multilevel Inverter based Shunt Active Filter”** submitted by Mandava Divya Prafulla **(Roll. No. 710EE2008)** in partial fulfillment of the requirements for the award of Master of Technology Degree in **Electrical Engineering** with specialization in **“Power Control and Drives”** at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him/her under my/our supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

Prof. Anup Kumar.Panda

Deptt.of Electrical Engg.

National Institute of Technology

Rourkela –769008

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ABSTRACT

Harmonics have become a major issue in the recent times due to the high usage of power electronic equipment. Harmonics lead to many problems such as overheating of equipment, interference with the near, by communication lines, high power loss, low power factor and hence poor usage of equipment. Shunt active filters are used to compensate these harmonics and draw only fundamental component of current from the supply. The shunt active filters be designed using multilevel inverters are more efficient when compared to the classical inverters due to their step voltage waveform.

In this work, multilevel inverter based shunt active filters are designed using different controllers such PI and fuzzy logic controllers. There is no requirement of a precise mathematical model when fuzzy logic controllers are used for their design unlike the PI controller. A three level H-bridge was used as the inverter for the filter design. The instantaneous active(i_{Ld}), reactive(i_{Lq}) components of load current are used to produce the reference compensation currents in this I_d-I_q control method. Matlab simulation was used to verify the results.

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Chapter 1

Introduction

1.1 Power Quality

Power quality is becoming a major issue in modern day power equipment because of the high usage of power electronic devices. The pollution in the equipment is mainly due to the nonlinear characteristics of the devices. They cause various problems like voltage distortion, current distortion, low power factor, interference in the nearby communication networks etc. in the form of harmonics. These harmonics are responsible for over-heating of equipment, noise or vibrations and may even cause damage. Due to the various problems caused due to the power quality issues, there is an urgent need for improving the power quality thereby reducing losses [1].

1.2 Literature Survey

Toward the end of 19th century the advancement of alternating current (air conditioning) transmission framework was in view of voltage which is sinusoidal of consistent frequency era. These voltages of consistent frequency are responsible for the configuration of transformer, transmission lines and machines [1]. In the event that the voltage will be non-sinusoidal then it will make numerous changes in the configuration of transformer, machine and transmission framework. Routine power hypothesis was taking into account active, reactive and apparent-power definitions were adequate to investigation and out lining of all the power frameworks. By and by, a few papers were distributed in the 1920s, demonstrating the ordinary idea of apparent power and reactive and its value under non-sinusoidal conditions. Fryze (1932) characterized power in time area while for frequency area was done by Budeanu (1927). Power quality has been becoming a very important criterion due to the high usage of power electronic equipment. Connection of nonlinear loads is mainly leading to this problem of voltage or current harmonics. [2]

When there is a flow of harmonics through the electric transmission lines or distribution systems there will be an additional distortions in voltage mainly because of the impedance present in the system. Therefore while generating and utilizing power there is a distorted voltage or current waveform [3].The currents in the grid system must operate at unity power factor to transfer maximum amount of power [4] There was usage of passive filters in the olden days for compensation, but these filters had many draw backs like heavy size, tuning problems, resonance etc. and they had to be replaced with active filters.[5] The shunt active filters used VSI for their operation.

The traditional two-level VSI systems used as APFs were the split capacitor three-leg or four-leg type. These models were only useful for low or medium power utilities. These drawbacks led to the invention of multilevel inverters which could be used for both high voltage as well as medium power applications[5,6] In the recent times multilevel inverters had been under attention mainly due to their usage in batteries, wind turbines etc. which could be connected through the inverter to the grid and reducing harmonic problems[7,8]. They were also a means to give a multilevel stepped voltage source inverter for connection to an AC high voltage, high power system for various applications like the photo voltaic, fuel cells, utility interface systems [9, 10]. Multilevel converters, mainly the three-level inverters, were the best tradeoff solution between cost and performance for high-power systems with high voltage[11,12,13] Points of interest of

PWM controlled VSCs, for example, diminished line harmonics, a superior power component, generously littler filters, and a higher framework productivity empower an expense decrease of the framework in numerous applications, for example, rolling mills, marine and mining applications, electrolysis and high voltage dc transmission.[15,14] In high power applications particularly with high voltage, conventional two-level VSIs couldn't dodge to utilize the arrangement of series connected semiconductor switches to adapt to impediments of system rating used and it might be exceptionally bulky and even tricky essentially because of the trouble of system matching deteriorating utilization factor of switching devices.[16] When properly designed shunt active filters solves this problem by working as current source by supplying negative harmonics . Harmonic currents which have opposite phases to those of the harmonic currents drawn from the source by the nonlinear loads are produced by the filter[17] The reference current extraction has to be done for design of filter and their compensation capabilities are not the same in every control strategy Some of them do not give a proper solution when the source voltage is not balanced.[18,19] Fuzzy logic controllers unlike the PI controllers does not require the precise scientific mathematical model regarding procedure that is under control.[20]

1.3 Motivation

Due to the various drawbacks of passive filters, active filters were developed for reducing the harmonics in the equipment having nonlinear loads. Uninterrupted Power supplies, variable speed drives, and all other types of rectifiers etc. all come under the nonlinear loads. When properly designed shunt active filters solves this problem by working as current source by supplying negative harmonics. Harmonic currents which have opposite phases to those of the harmonic currents drawn from the source by the nonlinear loads are produced by the filter. When coupled in parallel to that of nonlinear load all there is a reduction of harmonic content by such a shunt active filter. Fundamental component of current only is thus drawn from the network.

Voltage source as well as current source converters can be used in the filter design. Voltage source converters were found to be better over current source converters because they cost less and had higher efficiency than the latter. They could easily be cascaded for higher rating. Gating signals were given using different PWM techniques.

PWM was considered the most efficient technique for controlling the output of multilevel inverters. There are many different kinds of PWM techniques available. The most simple and commonly used technique is using a high frequency triangular carrier signal, and a reference signal. Both of them were compared using a comparator and the output was high when the reference signal value exceeded the carrier signal value and low otherwise. Many other techniques were also developed like the delta modulation, Space vector modulation, delta sigma modulation etc. Each of the methods have their own advantages over the others.

1.4 Objective

1. Study of multilevel inverter topologies and simulation of models with MATLAB/SIMULINK.

2. Modelling of shunt active filters for the reduction of the harmonics in the equipment using different controllers like PI and fuzzy controller.

3. Comparing the performance of the filter using different controllers.

1.5 Thesis Outline

The thesis work is organized into the following chapters besides the present chapter 1

Chapter 2 - Different multilevel inverter topologies were discussed and their applications were presented.

Chapter 3 - PWM techniques were discussed for giving the gating signals to the inverters.

Chapter 4 - Simulation results for the different multilevel inverter topologies were presented.

Chapter 5 – Shunt active power filter design techniques were developed.

Chapter 6 – Shunt active power filter was designed using the PI control.

Chapter 7 – Shunt power filter was designed using a fuzzy logic controller.

Chapter 8 – Matlab simulation results.

Chapter 9 – Conclusion and future scope.

Chapter 2

Multilevel Inverters

2.1 Introduction

Many of the industrial and commercial application require medium and high power equipment in the range of megawatt. For all such applications a single switch shouldn't be connected and so a family of switches have to be connected. This led to the introduction of multilevel inverters which can be applied effectively in high as well as medium power applications. These inverters are made up of an array of capacitors voltage sources, power semiconductor from which they tend to generate stepped output voltage waveforms [3, 4].

2.2 Multilevel Inverters

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In the recent times many different multilevel inverter topologies were proposed. There are mainly three different basic topologies which remain the basis for many of the recent ones proposed. They are

[1] Diode clamped or Neutral Point Clamped inverter multilevel

[2] Flying Capacitor or Capacitor Clamped Inverter

[3] Cascaded H-bridge Multilevel Inverter

2.2.1 Diode Clamped Multilevel Inverter

Here for this inverter model the clamping purpose is served by using a diode as in fig.2.1 to output the required staircase voltage waveform. Figure shows connecting series of capacitors in the 3 level diode clamped inverter. Multiple voltages will be provided for the M level inverter, each of the capacitor has a voltage of V_{DC}/m-1. Maximum output voltage which can be obtained is half of the input DC voltage. This has been the main drawback for this topology. But this problem can be overcome by increasing the number of switches, capacitors, diodes. Three level inverters of this type are extensively being used in industries these days.

Applications

- They are used for Harmonic compensation purpose [7].
- They are used for motor drives with variable speeds [8].
- High voltage DC, AC transmission lines use them [9].

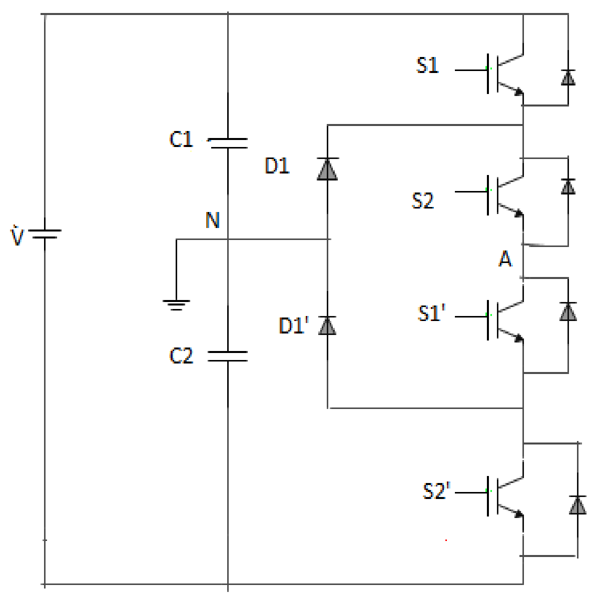

Figure 2.1 Diode Clamped Multilevel Inverter

2.2.2 Flying Capacitor Multilevel Inverter

This structure has series of capacitor clamped switching devices as in fig. 2.2[5]. This topology has many advantages over diode clamped structure. One of the main advantages is that it does not require additional clamping diodes. Unlike that of diode clamped structure where capacitors of same leg are charged to equal voltages. Here the capacitors are charged to different voltages. This is the main disadvantages which lead to the limited use of this inverter. Fig shows the 3 level capacitor clamped topology.

Applications

- Used in the control of Induction motor using Direct Torque Control (DTC) circuit[8]
- Used for harmonic compensation [7].
- Used in both AC-DC as well as DC-AC conversion applications [9].

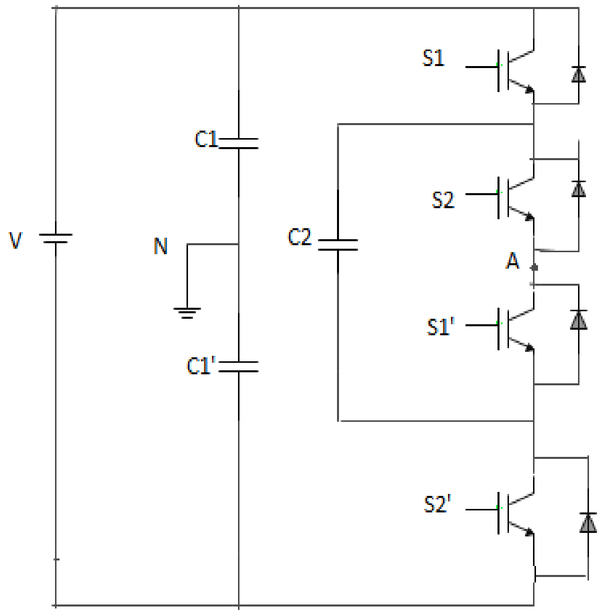

Figure 2.2 Capacitor Clamped Multilevel Inverter

2.2.3 Cascaded H-Bridge Multilevel Inverter

Multiple single phase full bridges are connected in series where each bridge can switch between $+V_{dc}$,0 and $-V_{dc}$ as in fig.2.3[6]. The voltage supply to each bridge is provided separately .The requirement of separate voltage supply devices is the main disadvantage of this model. Fig shows the 5 level H bridge multilevel inverter configuration.

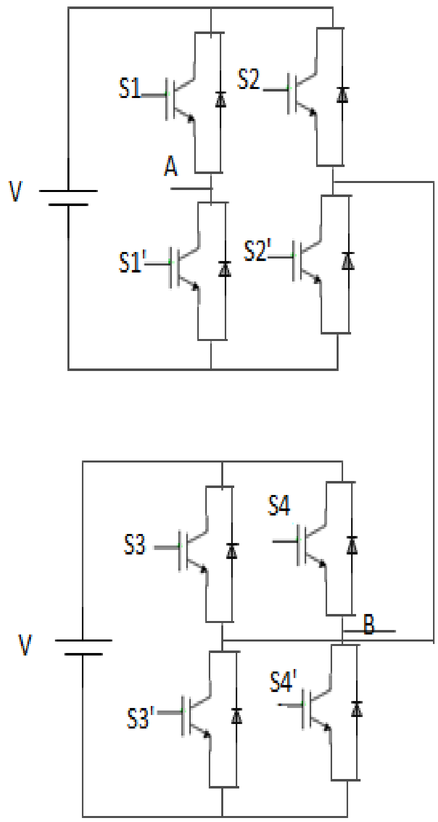

Figure 2.3 Cascaded H Bridge Multilevel Inverter

Applications

- They are used in Motor drives[8]
- Used in active filters
- They are used in electric vehicle drives.
- Used to compensate Power factors.
- Used for interfacing of the renewable energy sources.

2.3 Comparison between different topologies

Table 1

S.NO	Component	Diode-clamped	Capacitor Clamped	H-bridge
1.	Diodes for clamping	(M-1)*(M-2)	0	0
2.	Balancing capacitors	0	(M-1)*(M-2)/2	0
3.	Capacitors for the DC bus	(M-1)	(M-1)	(M-1)/2
4.	Semiconductor switches	2*(M-1)	2*(M-1)	2*(M-1)

2.4 Advantages

The multilevel converter topology has many advantages. Some of them are

1. They produce common mode voltages thereby reducing the stress on the motor and thus protect the motor from any possible damage [10].

2. Input current with very low distortions can be drawn.

3. These operate at both switching frequencies which could be much greater than the fundamental switching frequency or even very less than that of the fundamental switching frequency. A lower switching frequency always leads to lower loss and high efficiency.

4. The distortion in the output can be maintained extremely low using the selective harmonic elimination technique.

2.5 Summary

This chapter discussed about the main three types of multilevel inverter topologies available and their applications. Their advantages and drawbacks were discussed along with their applications in different equipment. Different configurations were compared at the end.

Chapter 3

Modulation Techniques in Multilevel Inverters

3.1 Introduction

PWM was considered the most efficient technique for controlling the output of multilevel inverters. There are many different kinds of PWM techniques available. The most simple and commonly used technique is using a high frequency triangular carrier signal, and a reference signal. Both of them were compared using a comparator and the output was high when the reference signal value exceeded the carrier signal value and low otherwise. Many other techniques were also developed like the delta modulation, Space vector modulation, delta sigma modulation etc. Each of the methods have their own advantages over the others.

3.2 Sinusoidal Pulse Width Modulation

The best among all the PWM methods is the Sinusoidal Pulse Width Modulation (SPWM) which can be implemented in two level as well as multilevel inverters. In this technique a sinusoidal reference signal and a carrier signal of very high frequency (triangular signal) are under comparison to give low or high output. There are 2 types of SPWM techniques i.e. unipolar and bipolar pulse width modulation. The bipolar technique requires a single modulating wave and a single carrier wave whereas unipolar modulation requires two sinusoidal waves and a single carrier wave. These techniques are mainly used for H bridge inverters.

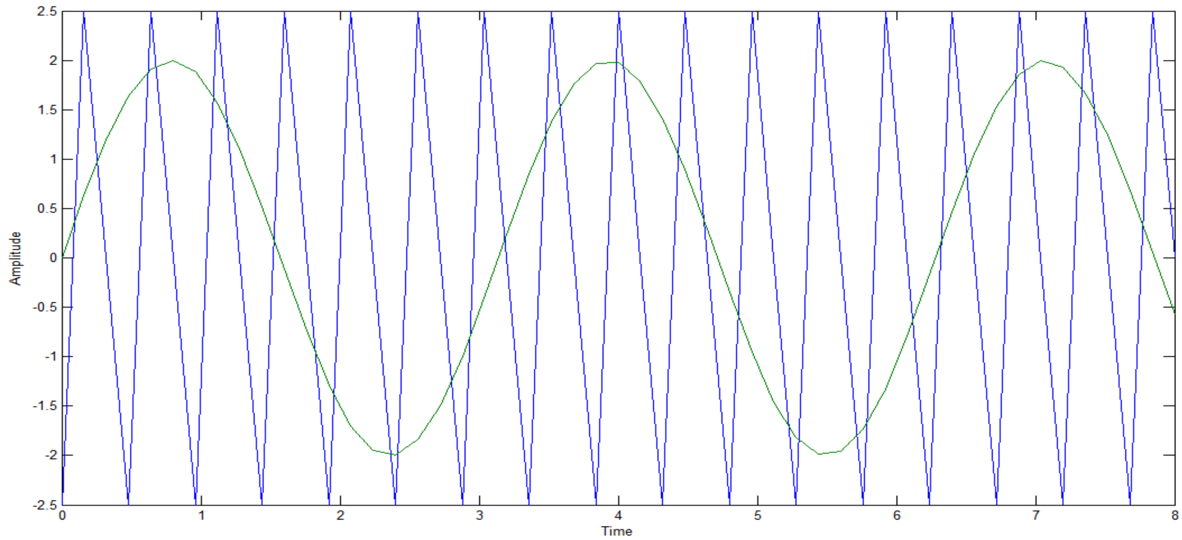

Figure 3.1 Bipolar Modulation Scheme

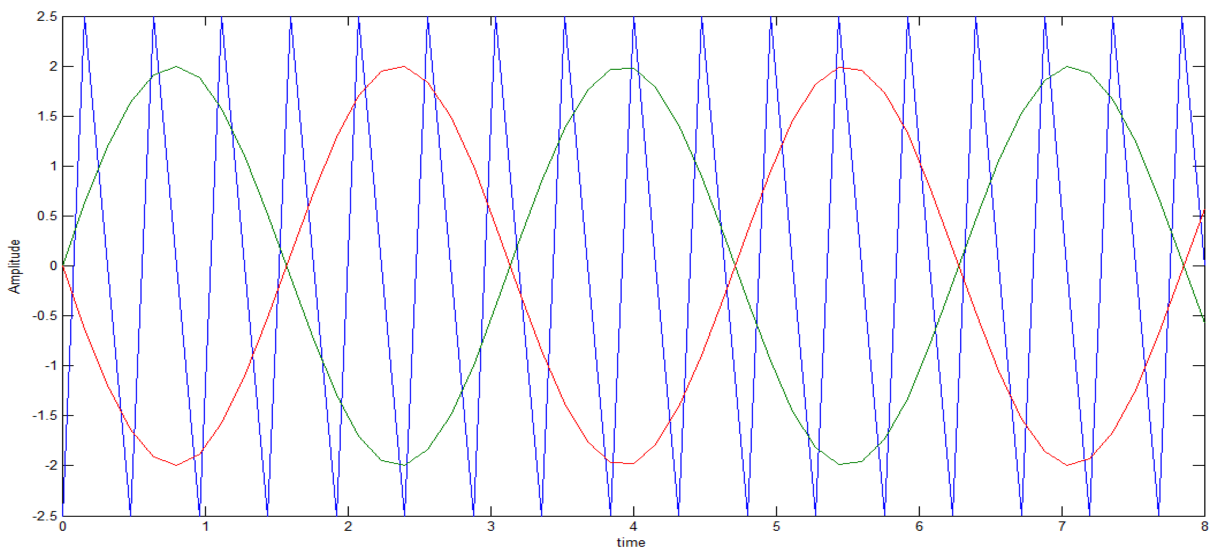

Figure 3.2 Unipolar Modulation Scheme

3.3 Multicarrier Pulse Width Modulation Techniques

Cascaded Multilevel inverters use PWM techniques which are mainly classified as 1. Phase shifted modulation and 2.level shifted modulation [11]. For both the techniques, (M-1) triangular carrier waves with that of same frequency and with same peak-peak amplitudes will be required for an M level inverter.

3.3.1 Phase Shifted Modulation**:**

Here, there will be a phase shift of ϕ_{cr} between all the adjacent carrier signals. There is a phase shift $\phi_r = \frac{360^\circ}{(m-1)}$.

3.3.2. Level Shifted Multicarrier Modulation**:**

In this technique all the triangular waves are vertically displaced as shown in fig.. Depending upon the disposition of the carrier waves it is further classified into

(i) In Phase Disposition PWM (IPD – PWM): In IPD -PWM all of carrier triangular waves have same phase as in fig 3.2

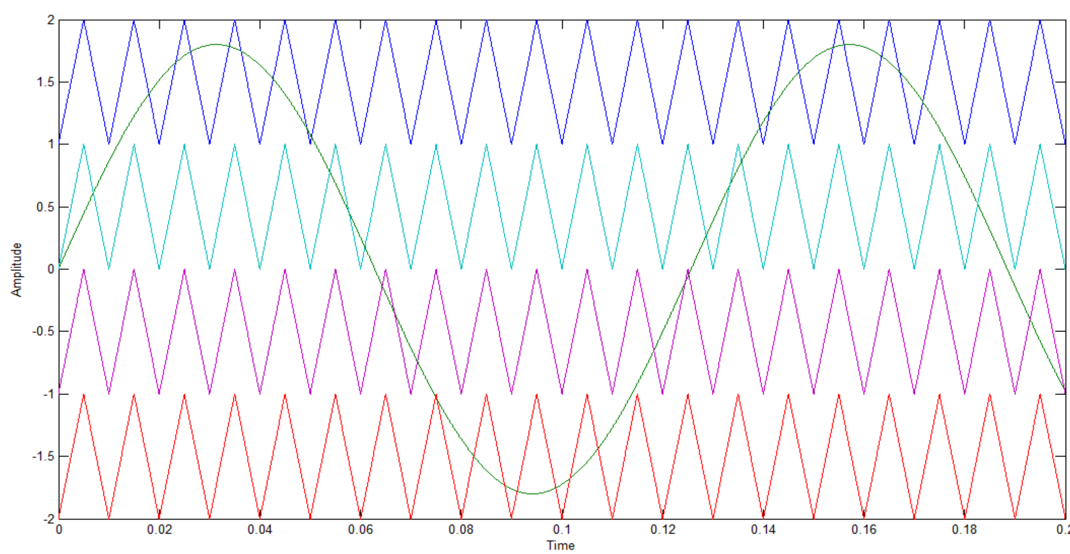

Figure 3.2 In Phase Disposition PWM Scheme

(ii) Phase Opposition Disposition PWM (POD – PWM)- Here the carrier waveforms will be placed above with those below the zero reference .There will be a 180 degrees phase shift in the ones below and the ones above zero as in fig 3.3 .

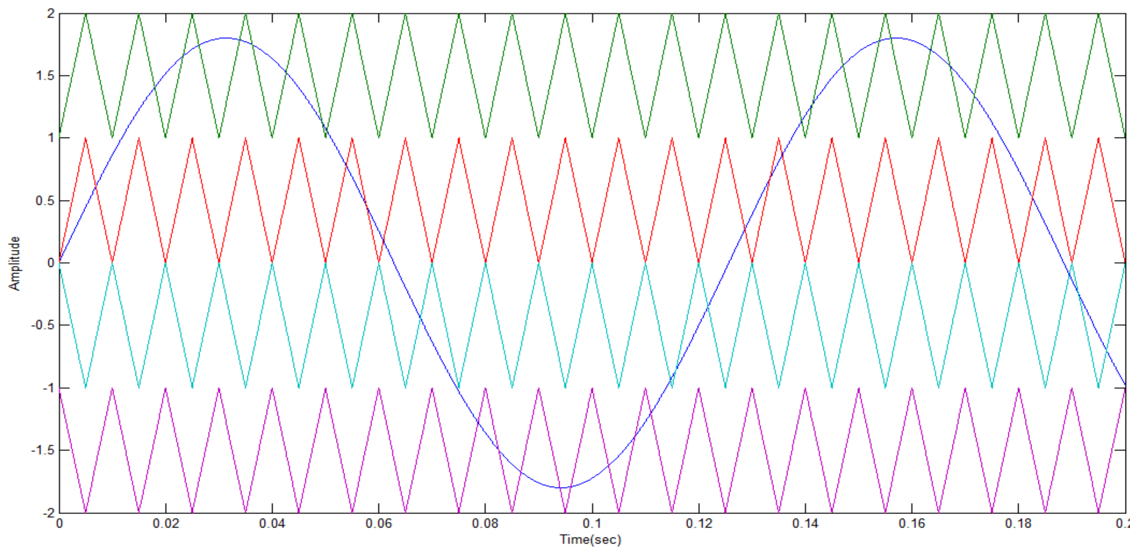

Figure 3.3 Phase Opposition Disposition

(iii) Alternate Phase Opposition Disposition PWM (APOD –PWM)- Here the carrier waves are to be 180 degrees displaced from each other alternately as in fig 3.3.

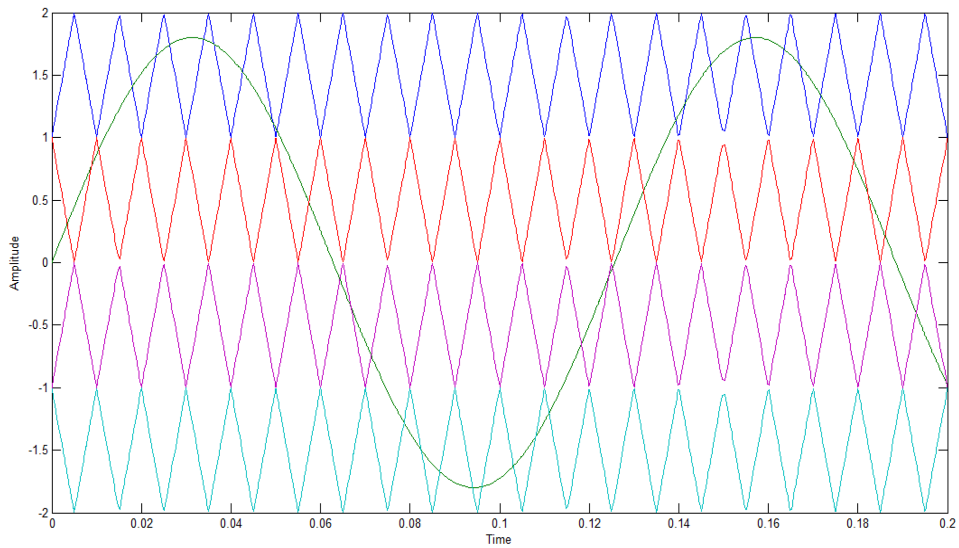

Figure 3. 1 Alternate Phase Opposition Disposition

3.4 Simulation Results for Multilevel Inverters

All the 3 types of multilevel inverter configurations were modelled and simulated in MATLAB/SIMULINK software using different multilevel PWM schemes.

Fig.3.3 and fig.3.4 shows the output voltage waveform for a 3 level diode clamped inverter using different PWM techniques.

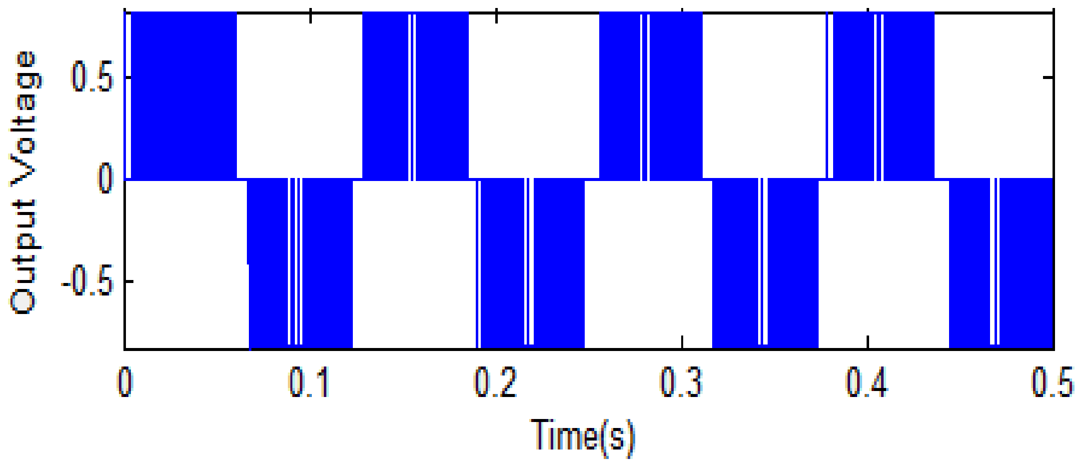

Figure 3.3 Output for 3 level diode clamped inverters using in phase disposition PWM technique

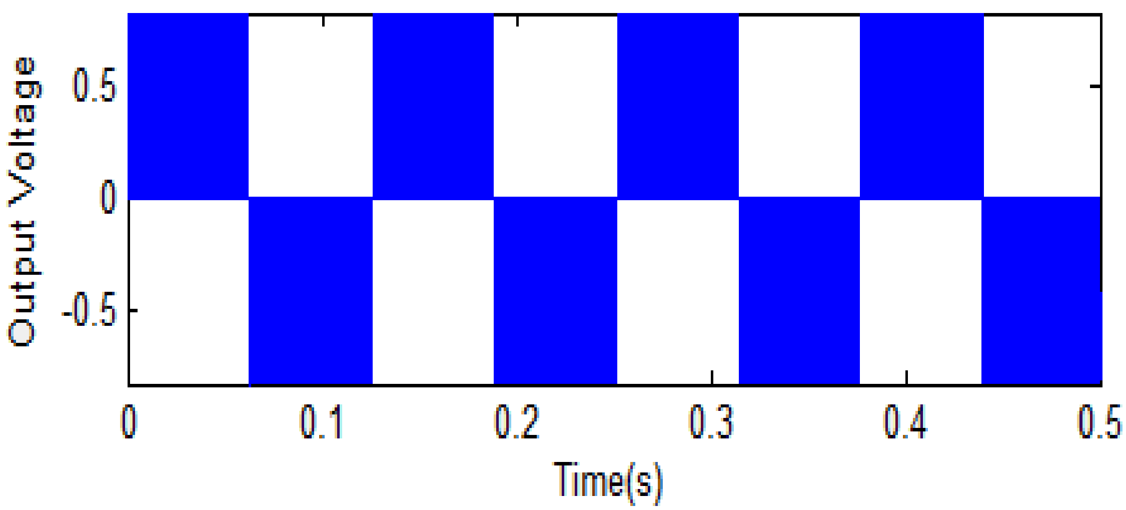

Figure 3.4 Output for 3 level diode clamped inverters using out of phase disposition PWM technique

Fig 3.5, 3.6, 3.7 show the output for 5 level diode clamped inverters using different PWM techniques. It can be seen the waveform that the output approaches more a sine wave here when compared to the 3 level inverter.

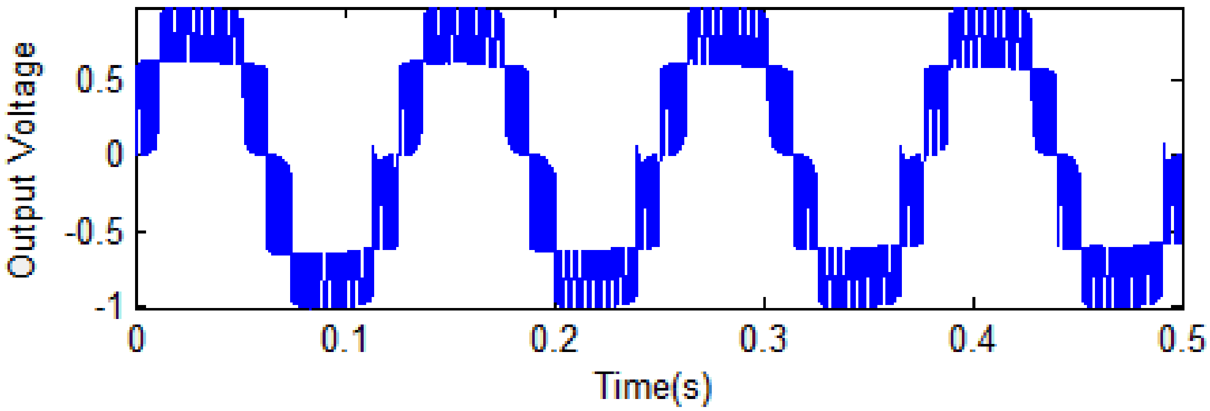

Figure 3.5 Output for 5 level diode clamped inverters using in phase disposition PWM technique

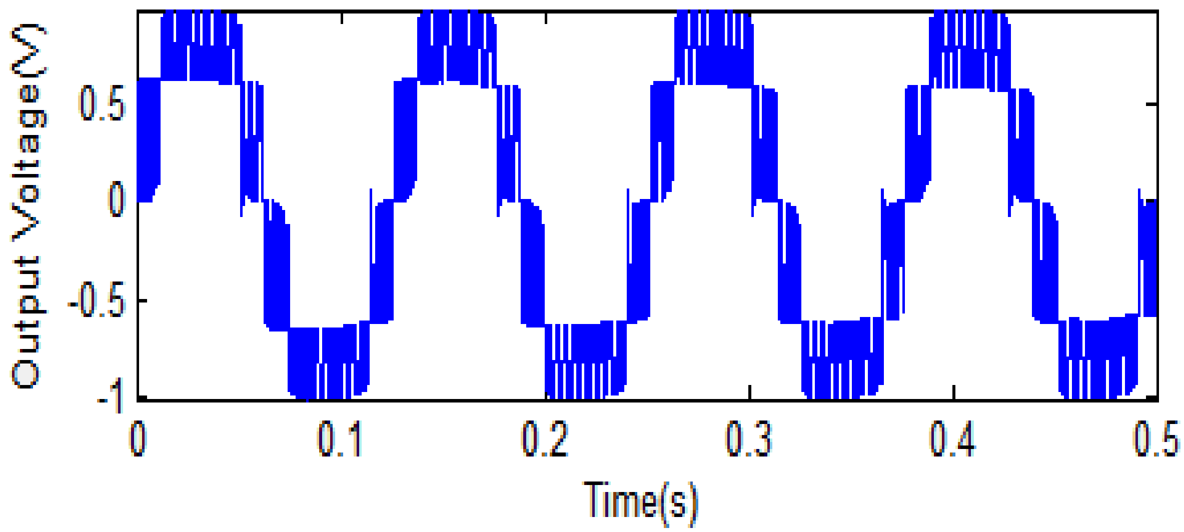

Figure 3.6 Output for 5 level diode clamped inverters using alternate phase disposition PWM technique

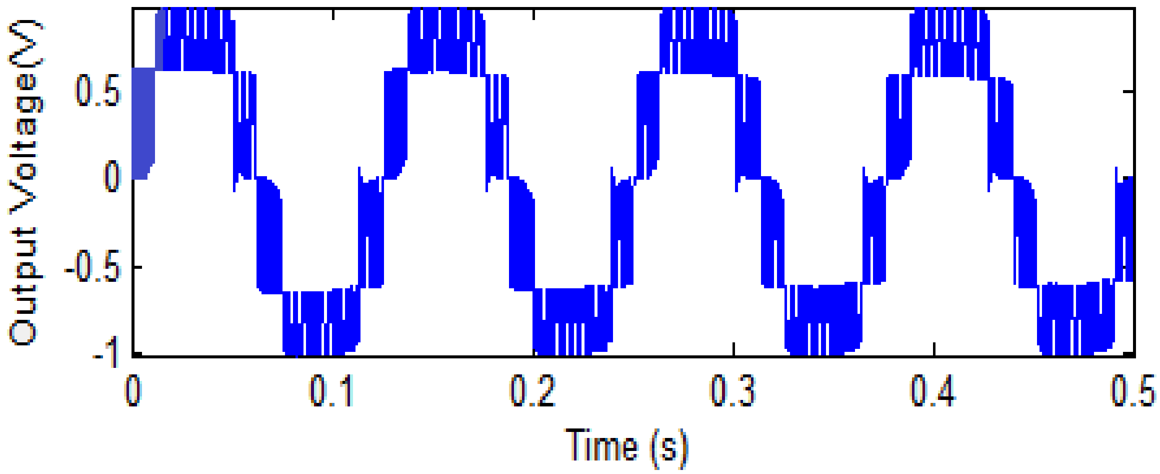

Figure 3.7 Output for 5 level diode clamped inverters using out of phase disposition PWM technique

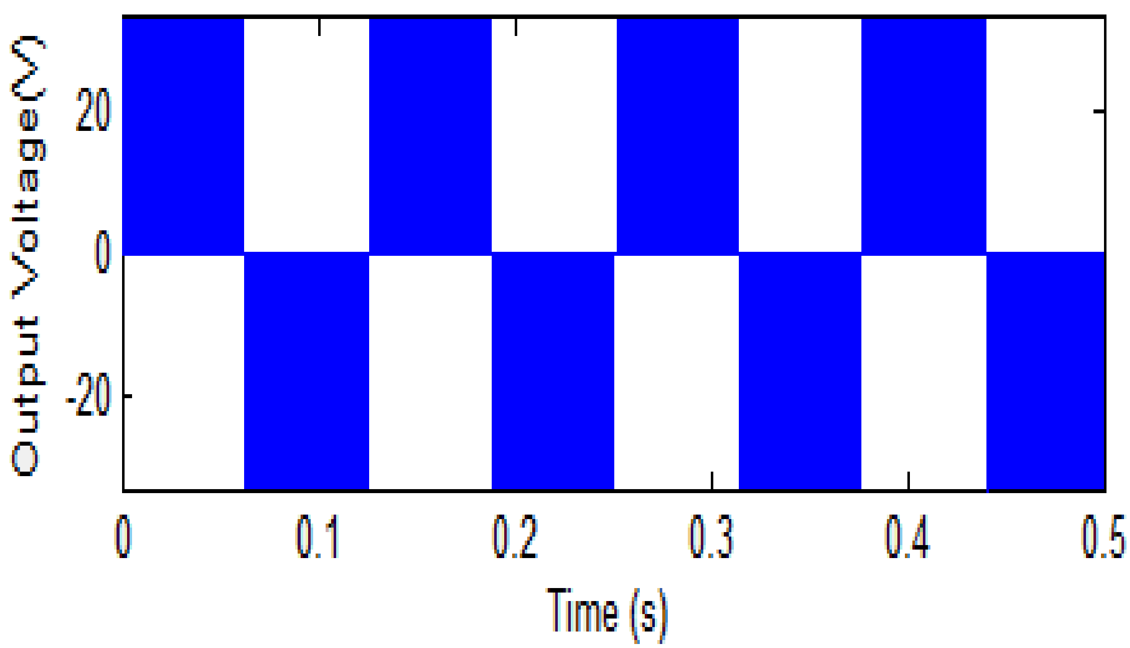

Figure 3.8 Output for 3 level capacitor clamped inverters using in phase disposition PWM technique

Fig 3.8 and 3.9 show the output for a 3 level capacitor clamped inverter using different PWM techniques

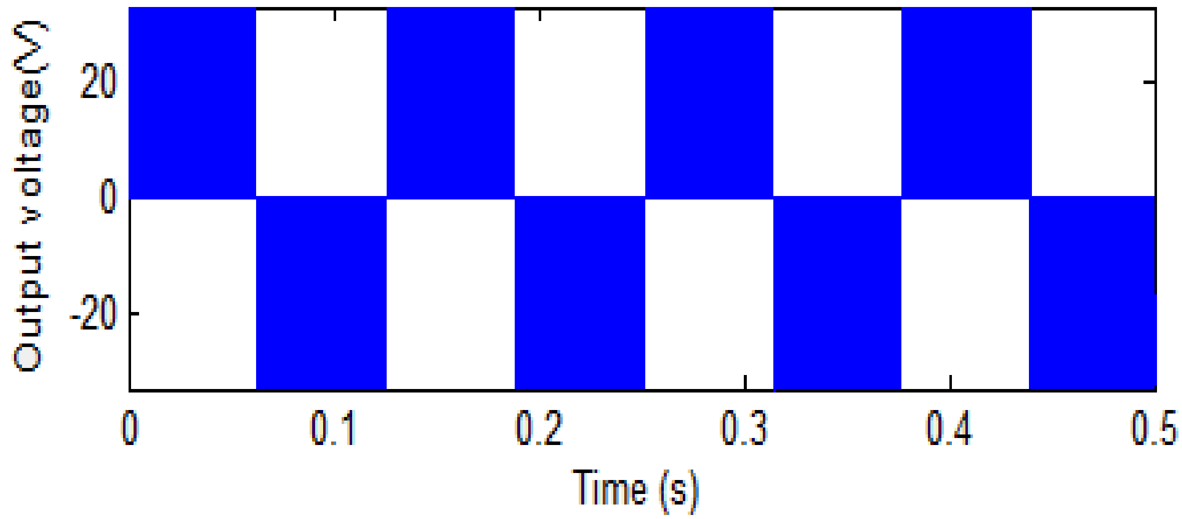

Figure 3.9 Output for 3 level capacitor clamped inverters using alternate phase disposition PWM technique

Fig 3.10 shows the output voltage waveform for a 9 level H bridge .It can be seen from figure that it gave a better waveform which is better approaching a sine wave when compared to the 3 level and 5 level waveforms.

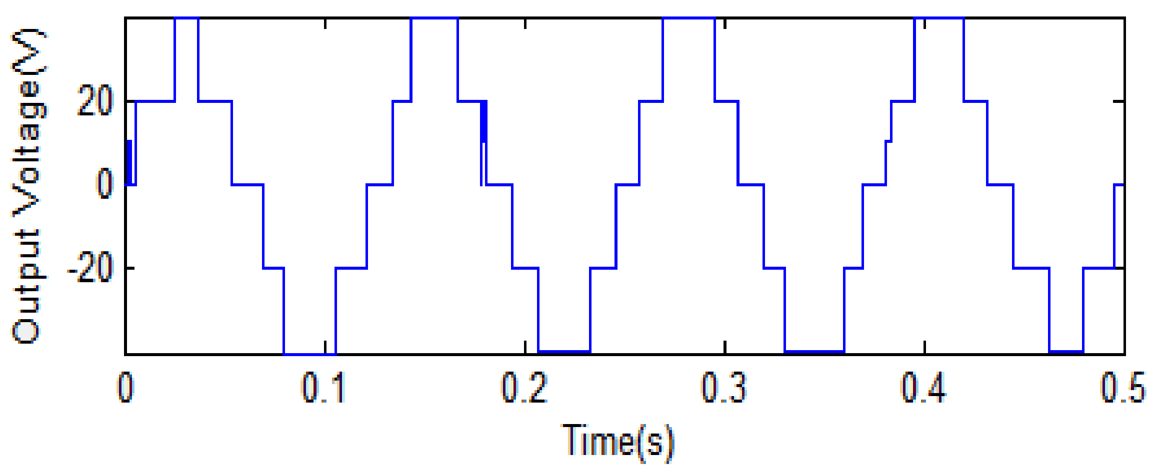

Figure 3.10 Output for 9 level H-Bridge

3.4 Summary

In this chapter the different PWM modulation techniques were presented for two level as well as multilevel inverters. Different sinusoidal pulse width modulation techniques for two level and multilevel inverters were discussed. Simulation results using MATLAB for 3 level and 5 level diode clamped inverter, 3 level diode clamped inverter, 9 level H-bridge are presented.

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Chapter 4

Shunt Active Power Filter

4.1 Introduction

Power quality improvement is becoming a major issue in modern day power equipment because of the high usage of power electronic devices. The pollution in the equipment is mainly due to the nonlinear characteristics of the devices. They cause various problems like voltage distortion, current distortion, low power factor, interference in the nearby communication networks etc. in the form of harmonics. These harmonics are responsible for over-heating of equipment, noise or vibrations and may even cause damage. Due to the various problems caused due to the power quality issues, there is an urgent need for improving the power quality thereby reducing losses.

For compensation of the non-linear loads generated current harmonics due to the, Conventionally LC passive power filters have been used, mainly because they were very cheap as well efficient[12] . But there were many drawbacks because of series and parallel resonances, their compensation largely depended on system impedance [12]. Source current harmonics are eliminated the impedance of filter must be smaller than that of the source. They are not suited for loads that vary with time, because the variation in load impedances have the possibility of detuning the filter [12]. Classically passive filters were used to improve the power quality. But these filters had many drawbacks like heavy size, resonance problems, fixed compensation etc. So active filters were developed to overcome these drawbacks. Many different active filter topologies were developed in the recent times. The active filter topology was found to be very effective even when there was high non-linearity in the load.

4.2 Shunt Active Filters

Uninterrupted Power supplies, variable speed drives, and all other types of rectifiers etc. all come under the nonlinear loads. They act as harmonic current sources because they draw non-sinusoidal currents from the source [12]. When properly designed shunt active filters solves this problem by working as current source by supplying negative harmonics. Harmonic currents which have opposite phases to those of the harmonic currents drawn from the source by the nonlinear loads are produced by the filter [12]. When coupled in parallel to that of nonlinear load all its harmonic currents will be compensated by such a shunt active filter. Fundamental component of current only is thus drawn from the network [12].

4.3 Basic principle

Conventionally the shunt APF's are controlled such that harmonic or reactive compensation currents are injected based on the reference currents calculated using different methods [13]. These currents which are injected have to cancel reactive currents and also the harmonics that are caused by non-linear loads. The desired reference currents that should be injected is determined by extensive calculations.

The filter is designed as in fig 4.1 below such that the system draws only fundamental component of current from the source and the harmonic currents are supplied by the filter.

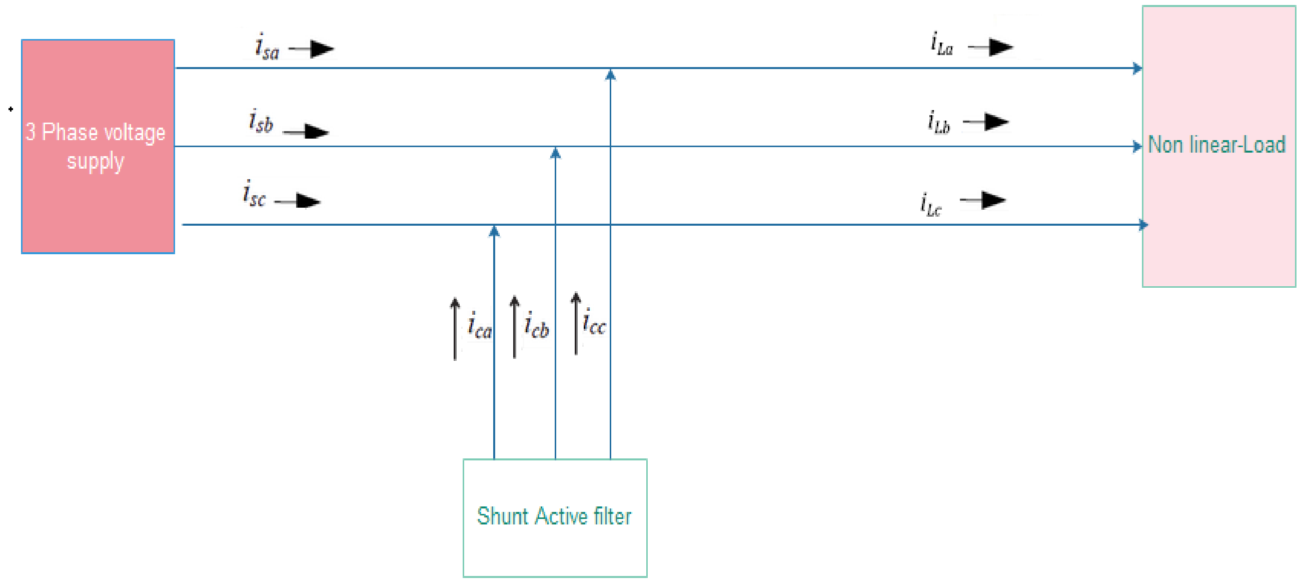

Figure 4.1 Shunt Active Power filter Block Diagram [12]

4.4 Shunt Active Filter Design

To achieve good compensation the filter must be able to extract and inject the harmonics maintain the DC capacitor link voltage constant $i_{Lc.}$ There are many different types of control strategies used to extract the compensation currents. Here we use the **"**Instantaneous active current and the reactive current "I_d-I_q" control strategy [2] which has many advantages over other methods. The instantaneous active (i_{Ld}), reactive (i_{Lq}) components of load current are used to produce the reference compensation currents i_{ca}*, i_{cb}* and i_{cc}* in this I_d-I_q control method [7]. The load currents are tracked and changed to stationary α-β reference and then into d-q using the parks transformation [7].

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \\ i_{L0} \end{bmatrix} = \sqrt{\frac{2}{3}} * \begin{bmatrix} 1 & -0.5 & -0.5 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \qquad \text{..........................} \; 1$$

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix} * \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 2$$

The angle theta can be obtained from the source voltage vectors for ideal source voltage conditions. [12]

$i_{Ld} = i_{Ldih} + i_{Ldnh}$ ………………………………………………………….. 3

$i_{Lq} = i_{Lqih} + i_{Lqnh}$ ………………………………………………………….. 4

$i^*_{cd} = -i_{Ldnh} + i_{d1h}$ ………………………………………………………….. 5

$i^*_{cd} = -i_{Lqnh}$ …………………………………………………………… 6

The fundamental component of d-axis and q-axis load current are filtered out and the harmonics along with the power loss component i_{d1h} are converted to reference currents.

The i^*_{cd} and i^*_{cq} are changed back to the a-b-c coordinates. Transformation M matrix of the equation $[i^*_{abc}] = [M]*[i_{Ldq0}]$ is given by equation 7 [7].

$$M = \begin{bmatrix} sin\theta & cos\theta & 1 \\ \sin(\theta - 2\pi/3) & \cos(\theta - 2\pi/3) & 1 \\ \sin(\theta + 2\pi/3) & \cos(\theta + \frac{2\pi}{3}) & 1 \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 7$$

4.5 Role of DC link capacitor

During dynamic load conditions the real power difference which must be supplied to the load is supplied by the capacitor by charging or discharging the capacitor. The DC link capacitor voltage must be necessarily maintained constant to achieve good working of the active power filter [13]. For this purpose a controller should be used. When DC voltage of capacitor is equal to that of constant reference value, then all the real power that is been drawn from source will be same as that of the power load the load consumes. When DC voltage of capacitor is less than that of the reference voltage, it implies that the active power demanded by the load and source current drawn by the equipment from the source must be increased because the source's output real power was not exactly enough to satisfy completely and a bigger value of DC capacitor voltage means that there must be a decrease in the reference source current.

4.6 Design using PI controller

4.6.1 Introduction

The PI (Proportional-integral) control mechanism is a feedback system extensively used for all industrial controls. The PI control system evaluates the error value (e) as the difference of the measured system variable with a reference variable. The controller tries to minimize the errors by use of manipulating variable thereby adjusting the process as per the requirement.

4.6.2 Filter Design

The PI controller algorithm involves two constants. The proportional and the integral values are denoted as k_p and k_i. The k_p value is based on the present error, and K_i is based on the past errors. The system process is controlled by taking the sum of the two through a control element.

The schematic diagram of the PI controller based filter is as shown in fig.4.2

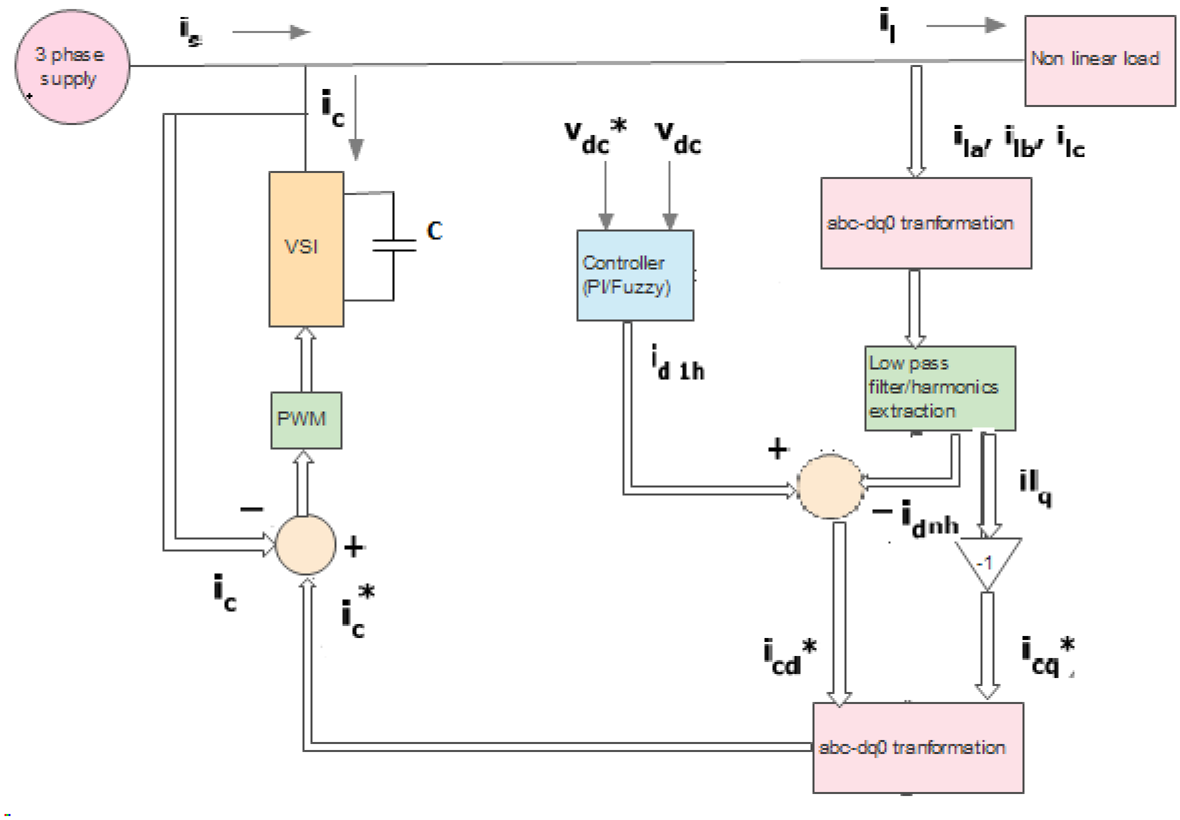

Figure 4.2 PI Control Scheme Block Diagram [12, 13]

The out value of that of the PI controller will be active current required to make up for the power loss inside the active filter is obtained by sending the error into the PI controller and thereby maintains the DC capacitor's voltage constant[18,19].

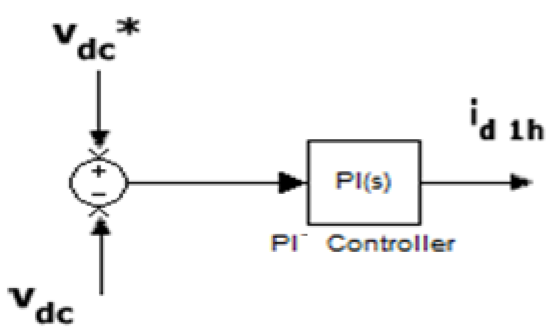

Figure 4.3 Internal Working of PI Controller [14, 15]

Using a comparator all the reference compensation currents thus which are obtained are compared with those of actual filter currents. Errors obtained are subjected to PWM using triangular carrier signals [20] and hence the obtained gate pulses are given to the VSI to obtain required compensation currents.

4.7 The fuzzy Logic control scheme

4.7.1 Introduction

Fuzzy logic is a type of numerous valued logic that can handle with surmised, as opposed to settled and accurate thinking. Contrasted with conventional parallel logic (where variables may tackle genuine or false values), the truth esteem of the fuzzy logic variables might have that lies in value somewhere around 0 and 1. It has been stretched out to handle the idea of incomplete truth, where reality quality may lie between totally genuine and totally false. Further when the linguistic variables are utilized, the degrees might be calculated by particular functions.

4.7.2 Design

Fig 7.1 demonstrates the procedure utilized for fuzzy logic control plan for the shunt active filter. The controlling model system diagram is as shown in the fig. For the implementation of the shunt filter control calculation, the voltage of the DC capacitor voltage ought to be measured and after that it is to be compared with that of the reference voltage [14].

The inputs for fuzzy system are the error(e) which is the difference of the values V_{DCref} and V_{DC} at nth sampling along with that of the change in error that is equal to ce(n)=e(n)-e(n-1) will be given as. Output of the fuzzy controller will be the active current needed to make up for all the power loss inside the filter and subsequently will keep the DC capacitor voltage constant. The reference currents for compensation acquired from the controller are compared to that of the original currents by utilizing a comparator. These errors are then subjected to PWM by using triangular carrier signals [14] and the obtained gate pulses are thus given to the VSI to obtain the required compensation currents.

4.8 Fuzzy Algorithm

The control activity of that of a fuzzy logic controller is primarily gotten from assessment of a set which contains straightforward simple rules. For the advancement of every one of these standards we require good understanding of the procedure which should be controlled however does not require the precise scientific mathematical model regarding procedure that is under control. The inward structure of the controller and the essential calculation utilized for the fuzzy controller is as demonstrated in the fig 4.2.

The fuzzy rationale framework basically comprises of the detailing of mapping of a given data set which is the input to the required output data set using fuzzy logic. The mapping procedure is the premise from which the conclusion will be made. The fuzzy procedure follows the following essential steps [6]:

1. Fuzzifying of the input variables
2. Applying of fuzzy operators such as AND, OR, NOT.
3. Defuzzification of the variables.

All the fresh inputs are firstly changed over to semantic variables in the fuzzification procedure in view of the membership functions (MF). A MF is fundamentally a bend that characterizes how the estimations of the fuzzy variable in the specific area are mapped to another MF μ which lies somewhere around 0 and 1. A Membership function may have distinctive shape figure. The most basic utilized state of the MF is the triangular-sort which could be symmetrical or asymmetrical. The trapezoidal MF has the shape of that of a truncated triangle. Firstly, two MFs are based on a Gaussian distribution curve: the essential Gaussian cure with a two-sided composite of two distinctive Gaussian distribution curves. The bell MF with a level top is to some degree not the same as a Gaussian. The Gaussian and also the bell MFs are both smooth and non-zero for all points which are non-zero [3].

The essential Boolean logic properties are likewise true for Fuzzy logic. We will know the extent to which every of the antecedent part of the standard will be fulfilled after all the inputs have been fuzzified. In light of this guideline, operations, for example, OR or AND are applicable on the fuzzy variables. [3].

The consequent part of the rule is evaluated with the help of the Implication part of the process. There are myriad implication methods proposed in the literature. Among all the methods Mamdani was one of the frequently used [3].

Results of the fuzzy output which are thus obtained from that of the implication and aggregation steps. The output will be union of that of all the outputs that is of that of all the individual rules. defuzzification process is the conversion from fuzzy output into that of a crisp output. For this process there have been many methods used .Of all the defuzzification methods Center of Area (COA) is frequently used [3].

For this scheme, the error (e) along with change of error (ce) are inputs to the real system from. For the conversion of the input variables into the output variables, the seven fuzzy levels are thus chosen as: NB,NM,NS,Z,PS,PM,PB (negative-big, negative-medium ,negative-small , zero, positive-small ,positive-medium ,positive-big) [3,17] .

The elements for the rule table are obtained from good analyzation of the filter behavior as shown in table 2.

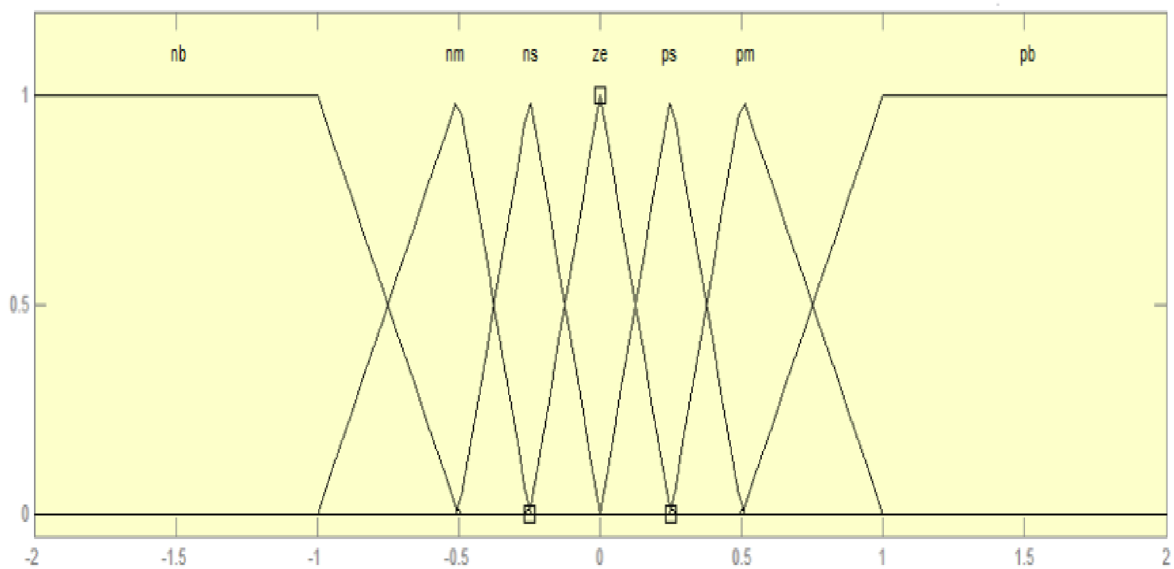

Figure 4.4 Input Error Membership Function [16]

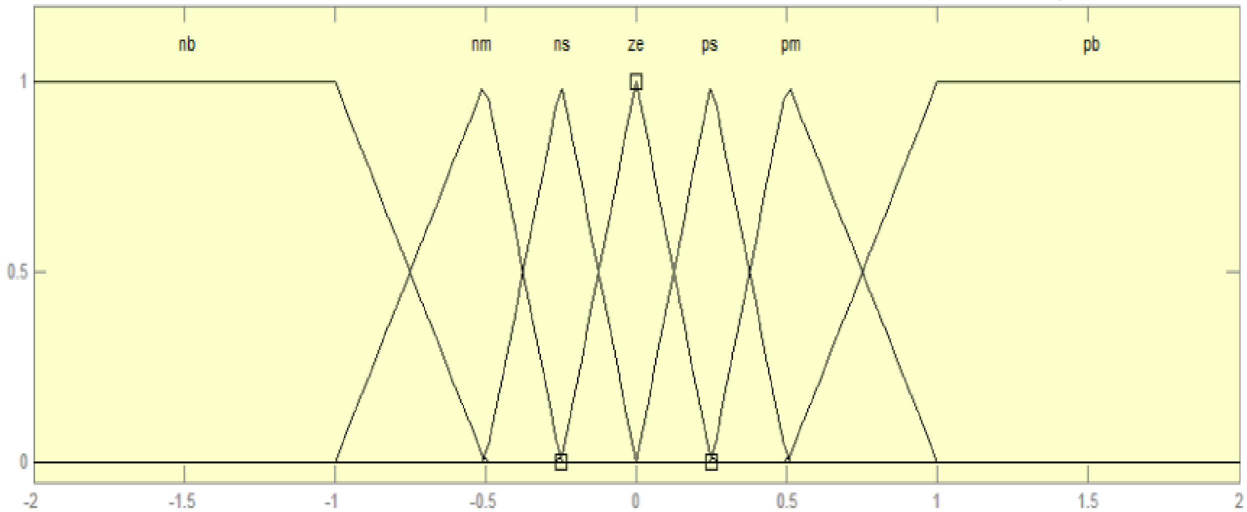

Figure 4.5 Input Change in Error Membership Function [16]

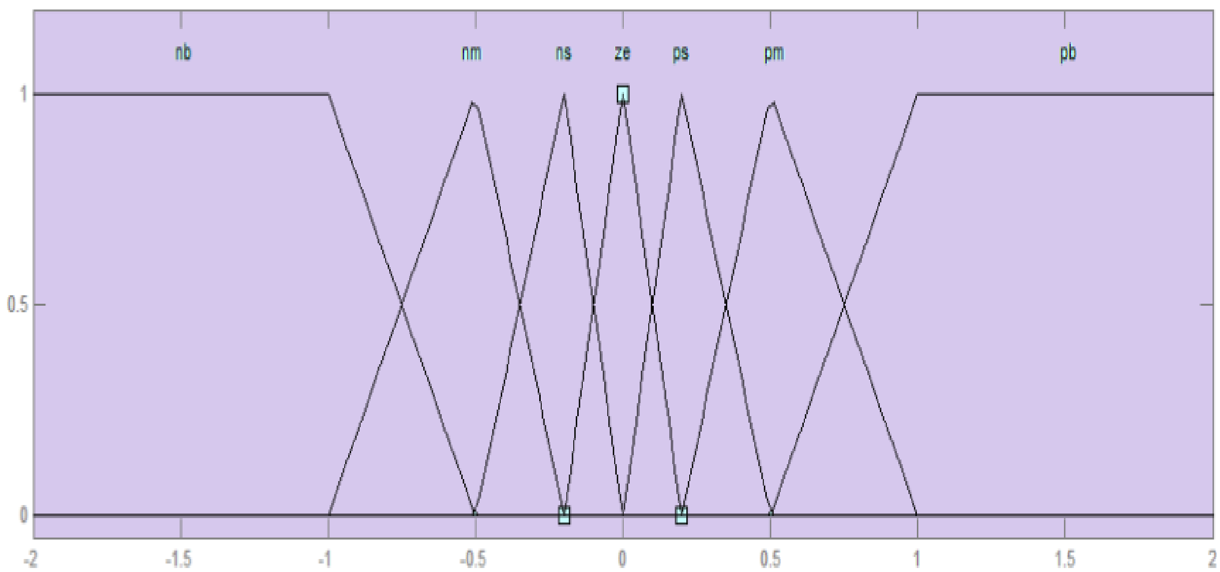

Figure 4.6 Output Current Membership Function [16]

Table 2 [17]

ΔError/Error	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PM	NS	Z	PS	PM	PB	PB	PB
PS	Z	PS	PM	PB	PB	PB	PB

4.9 Summary

The importance of the shunt active filter and its advantages over classical passive filters were discussed in this chapter. The designing and calculation of compensation currents using the "I_d-I_q" control strategy, role of DC link capacitor in maintaining good power quality was considered. Shunt active filter design utilizing the PI control and a fuzzy logic control were presented. Fuzzy logic was a better scheme than the PI control as it did not require a precise mathematical model for its design.

Chapter 5

Simulation results and Discussion

5.1 Simulation Results

A 3 phase system was taken and the active filter was modelled accordingly in MATLAB/SIMULINK software using both the controllers. A diode bridge rectifier was taken as the nonlinear load. The filter was designed using a 3 phase 3 level H bridge multilevel inverter. Fig 5.1 shows the balanced source voltage waveform. Fig. 5.2 shows the load current waveform for the non-linear load without using a filter. It can be observed from the figures below that the load current contains harmonics and is not a pure sine wave.

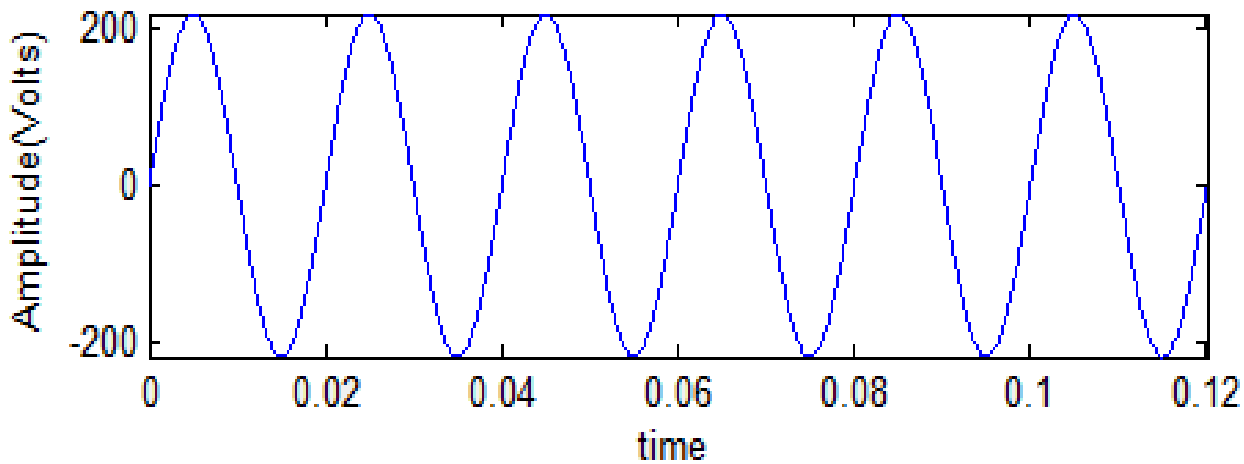

Figure 5.1 Source voltage Vs Time

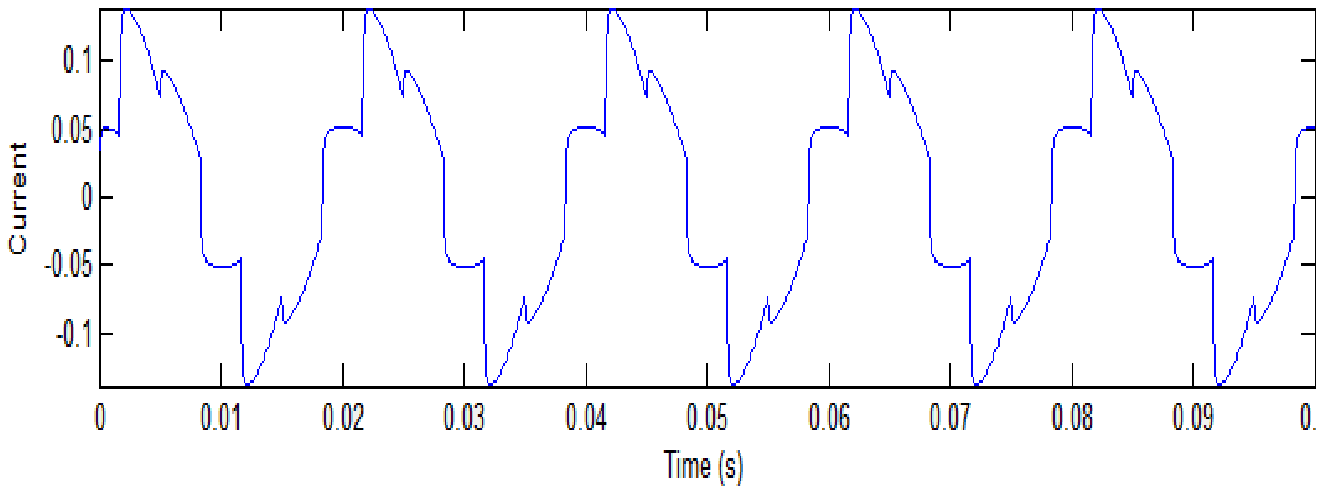

Figure 5.2 Source Current without using filter Vs time

Fig 5.3 shows the load current waveform after using a PI controller based shunt active filter which is sine wave.

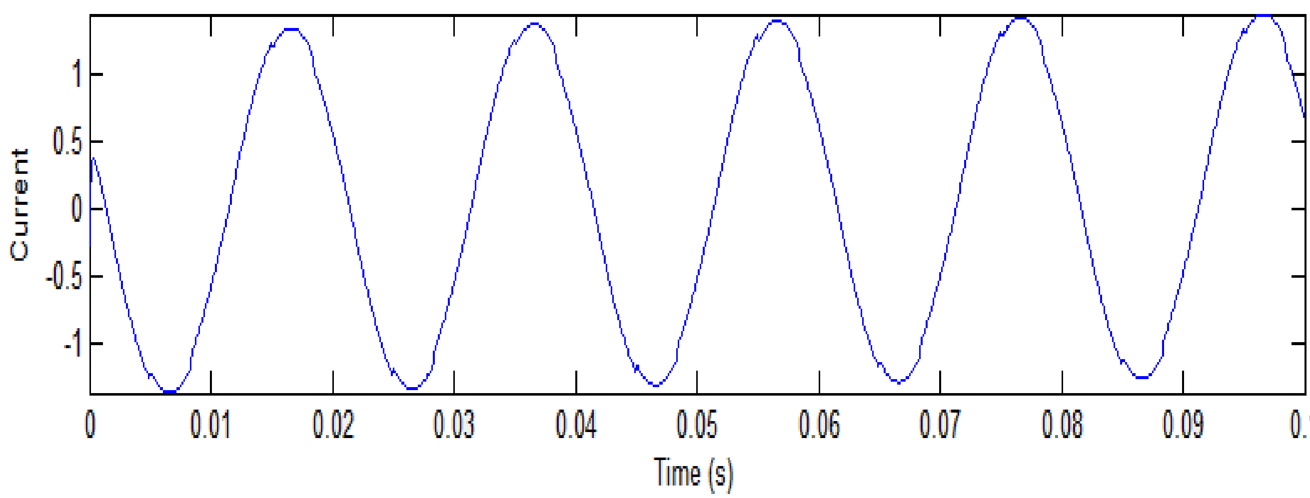

Figure 5.3 Source current after using PI controller based filter Vs time

Fig 5.4 and fig 5.5 show the THD analysis of the source current without using a filter and after using a shunt active filter. It can be observed from THD values that the harmonics were drastically reduced from 26.33% to 3.01%.

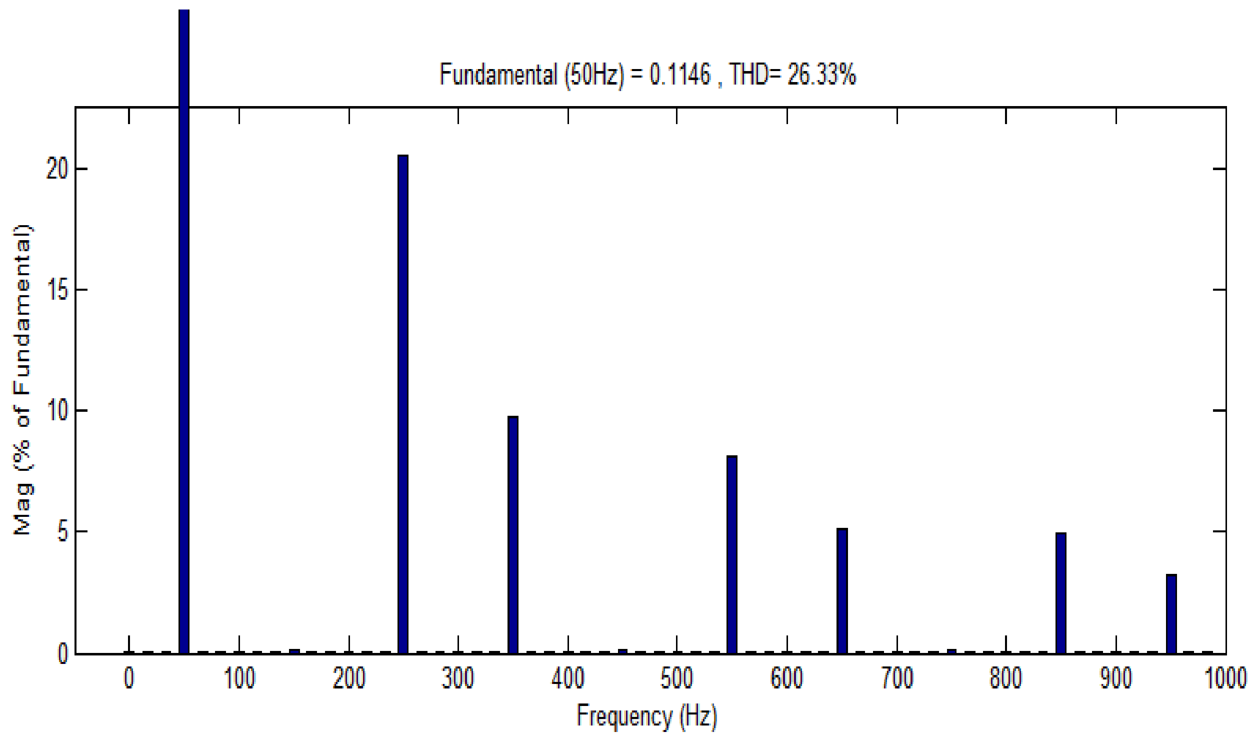

Figure 5.4 Source current harmonic spectrum before compensation

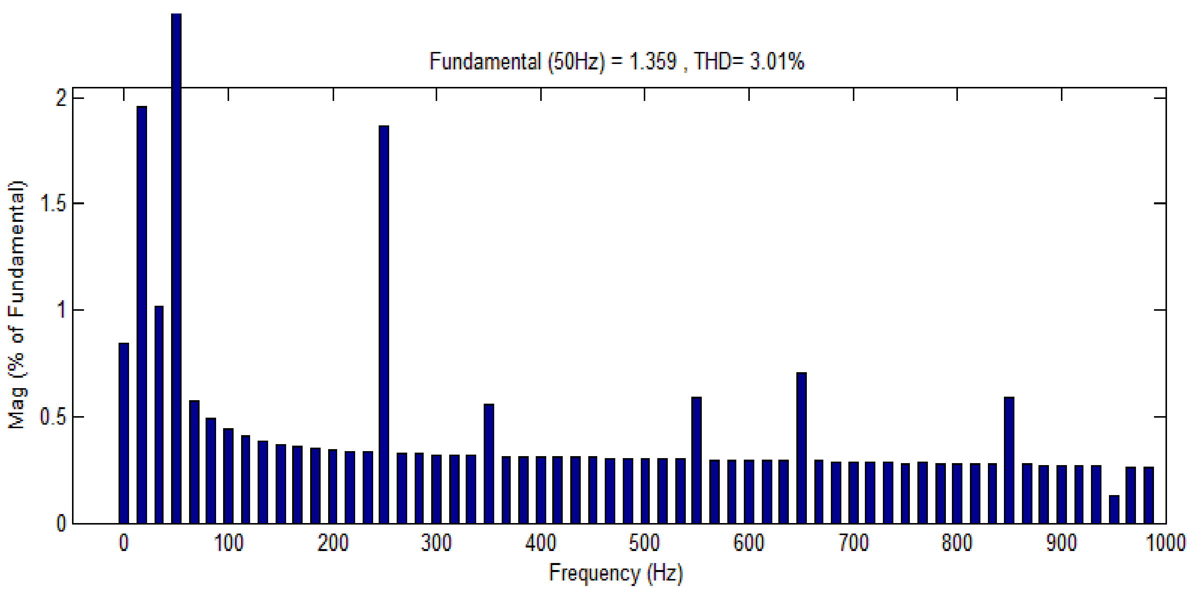

Figure 5.5 Source Current Harmonic spectrum after Using PI Controller Based Filter

Fig 5.6 shows the source current waveform after using a fuzzy logic controller based shunt active filter. It can be seen from figure that it does not contain harmonics. Fig.5.7 shows the THD analysis of the current waveform and it can be seen that the THD was reduced to 1.36% which was much less than that of the PI controller based filter.

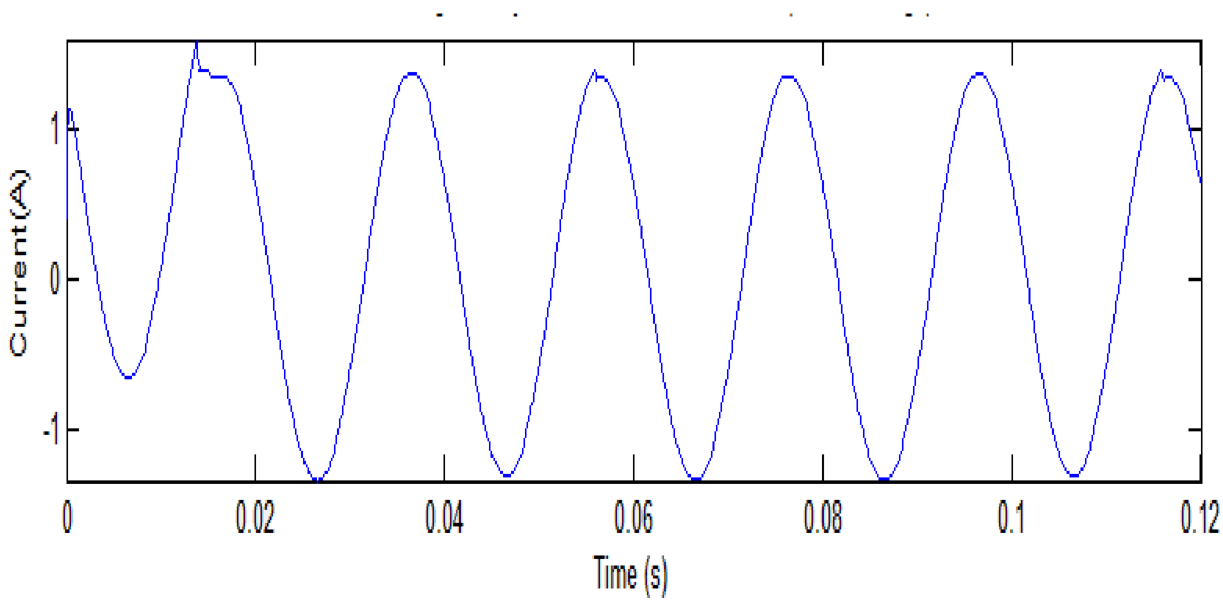

Figure 5.6 Source current after using fuzzy controller based filter Vs time

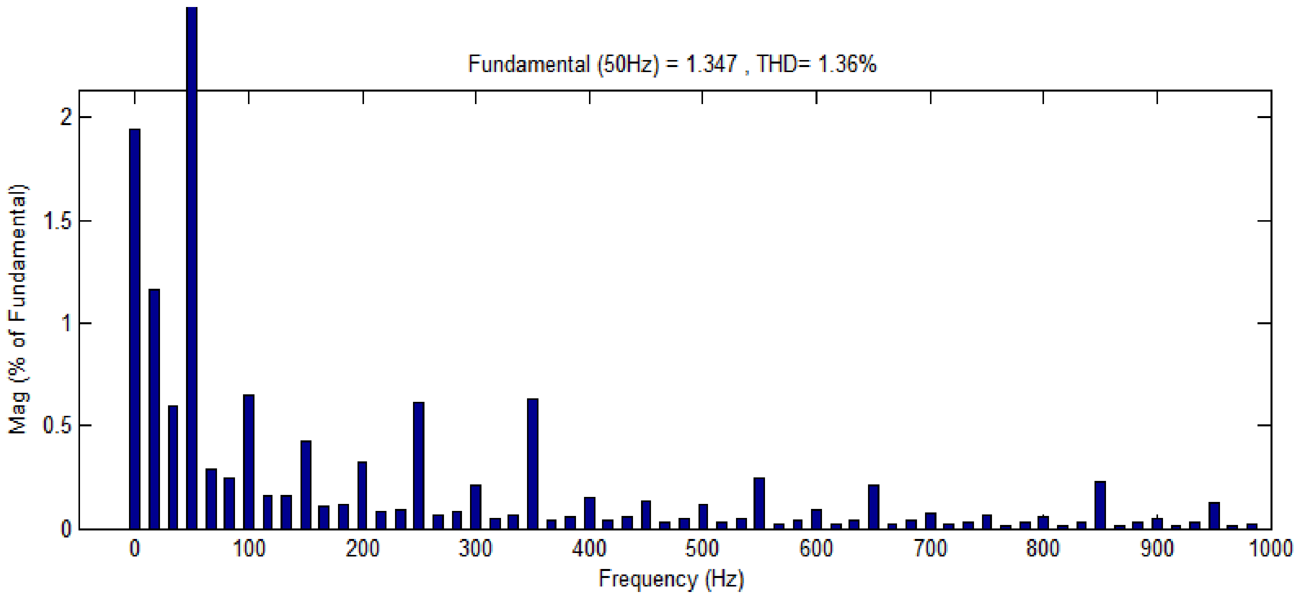

Figure 5.7 source current harmonic spectrum after using fuzzy logic controller

5.2 Summary

Simulation results using MATLAB/SIMULINK software for the design of shunt active filter using PI and fuzzy logic controllers were presented here. The harmonic distortion was also presented for each of the configuration. The fuzzy controller gave a better result when compared to PI controller based filter.

Chapter 6

Conclusion and Future Scope

6.1 Conclusion

In this work the multilevel inverter based shunt active filter was designed and verified using MATLAB software. Initially different multilevel configurations were modelled using MATLAB and the output was obtained. Level shifted PWM techniques were used to give the gating signals. It was found that as the number of number of levels increased, the output was found to have less harmonics and its shape was more resembling a perfect sine wave. The I_d-I_q control strategy was used to produce the reference currents for compensation. It was found to be a much better technique as it does not require a phase locked loop to obtain the compensation currents like other methods. Three level H-bridge was used in the design of the filter. Maintaining the DC link capacitor voltage constant was the main task in designing the filter and getting a harmonic free source current. Different controllers like the PI and fuzzy controllers were employed for this purpose. Using a comparator all the reference compensation currents thus obtained were compared with those of actual filter currents. Errors obtained are subjected to PWM using triangular carrier signal. The filters were designed using both PI and Fuzzy logic controllers. The THD was measured for both the models. The fuzzy controller gave a compensation of 1.36% and the PI controller gave a compensation of 3.1%. It was found that the fuzzy control scheme gave better compensation compared to the PI control scheme. Harmonics were drastically reduced with the use of filters and almost sinusoidal source current waveform was obtained.

6.2 Future Scope

1. Many different control strategies like the p-q strategy etc. can be used for the filter design.

2 .Controllers can be designed and verified for distorted source voltage conditions like distorted amplitude or distorted phase, dynamic load conditions. Practically since the loads are never constant, so the filters must be designed for varying loads.

3. Many advanced switching techniques are being developed which can be used to give the gating signals and obtain better output.

4. Use of many switching components which lead to a high cost of equipment in designing the multilevel inverters is the major challenge in the multilevel inverter based shunt active filter model. New topologies with less switching can be tries to be developed to overcome this problem.

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